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Title: Basics of Neutrons for First Responders

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# Basics of Neutrons

## For First Responders

Brian Rees

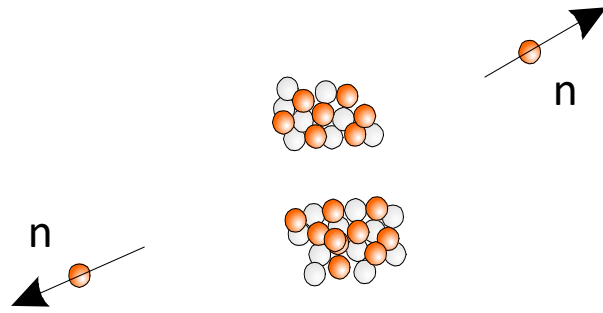
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# Basic stuff

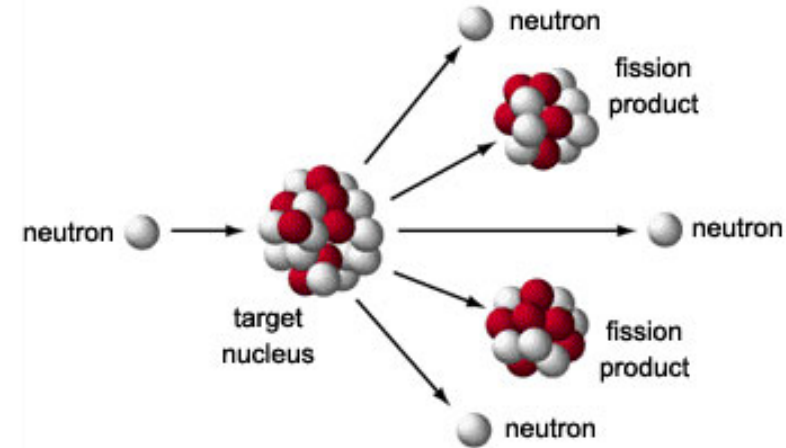
- Neutron mass 1.008664 amu
- Proton mass 1.007276 amu
- Electron 0.00054858 amu
- Half life 10.25 minutes

# Common Origins of Terrestrial Neutron Radiation

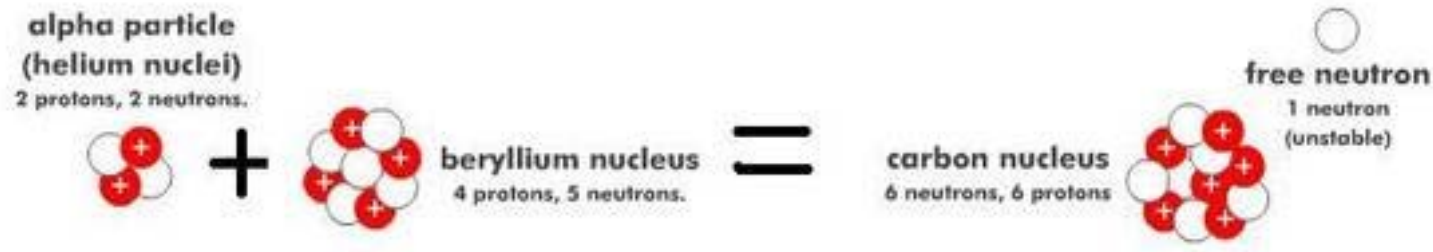
## Spontaneous Fission



## Induced Fission



## $(\alpha, n)$ Reactions



# Neutron Sources

- Reactors and fuel
- Particle Accelerators
- ( $\alpha$ ,n) sources: used in research and industry
- Transuranics: spontaneous fission (Pu, Cf-252)
- Natural Neutron Background:
  - Generally from 'cosmic ray' spallation
  - Very weak signal compared with natural gamma-ray background

Almost all neutron sources are man-made!

# Neutron energy

- Thermal neutrons      ~2200 m/sec (0.025 eV) 17° C (62° F)
- Epithermal      Faster than thermal
- Cadmium cutoff      ~0.5 eV
- Slow neutrons
- Fast neutrons      Fission mean energy ~ 2 MeV - 20,000 km/sec
  - D-T fusion      14.1 MeV – 52,000 km/sec
- Ultra fast      >~20 MeV

# Interactions

- Collide with protons
  - About the same mass
  - May displace the proton
    - Attracts an electron
    - Ionizes material
- Absorbed by another nucleus
  - Atom is stable
  - Atom is unstable
  - Energy may be released during or soon after reaction



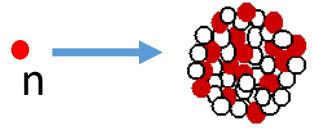
# Detecting Neutrons

- Absorption and nuclear reactions
  - He3
    - ${}_2\text{He}^3 + {}_0n^1 \longrightarrow {}_1\text{H}^3 + {}_1\text{p}^1$
  - BF3
    - ${}_5\text{B}^{10} + {}_0n^1 \longrightarrow {}_3\text{Li}^7 + {}_2\alpha^4$
  - Fission chambers
  - Other detectors
    - $\text{Li}^6$
- Moderation is key to most systems
- Liquid scintillators

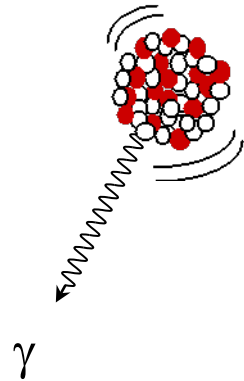
# Gammas from Neutron Interactions

## Neutron-Capture Gammas

Thermal neutron  
is absorbed by  
target nucleus.



Resulting nucleus  
emits a gamma  
ray.

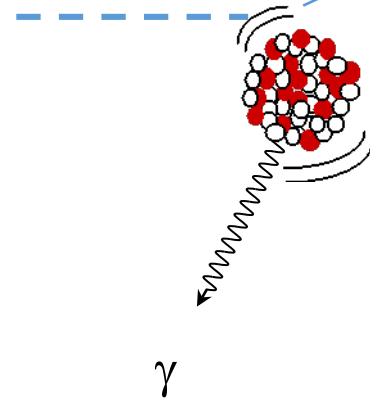


## Neutron-Scatter Gammas

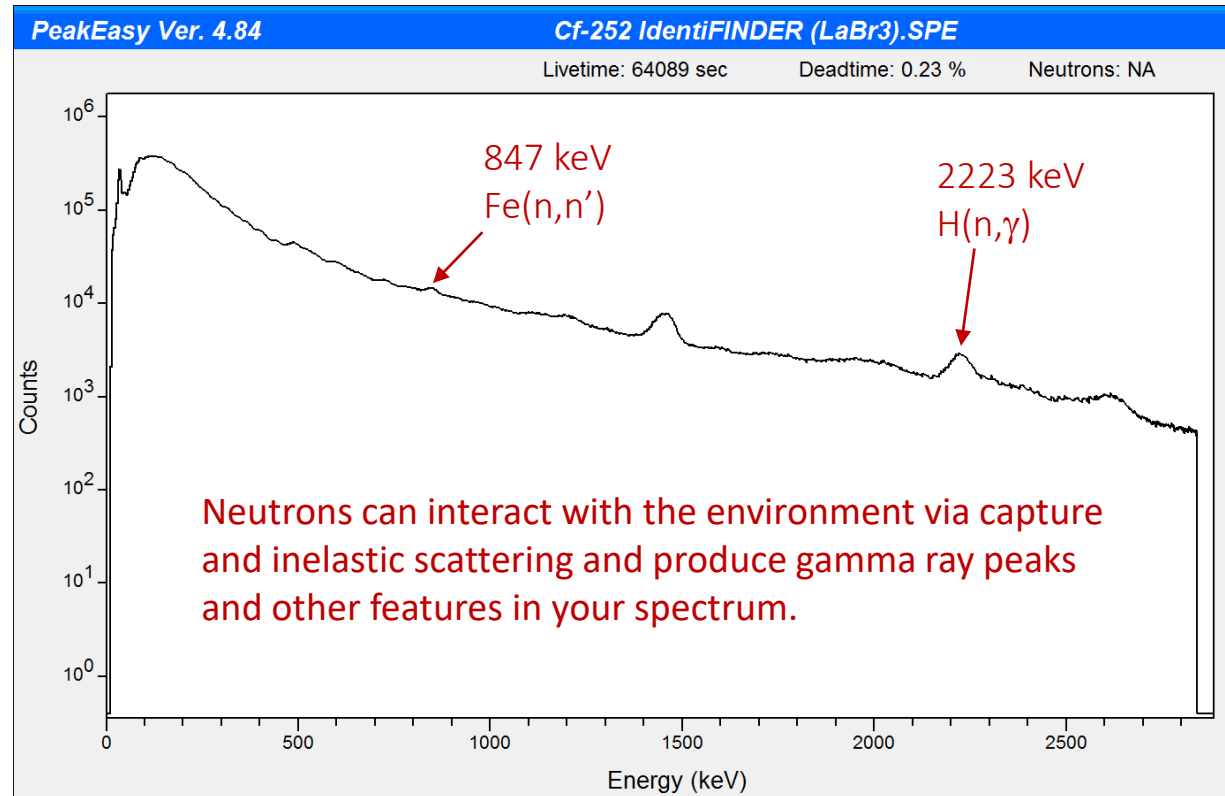
Fast neutron  
scatters from  
target nucleus.



Resulting nucleus  
emits a gamma  
ray.

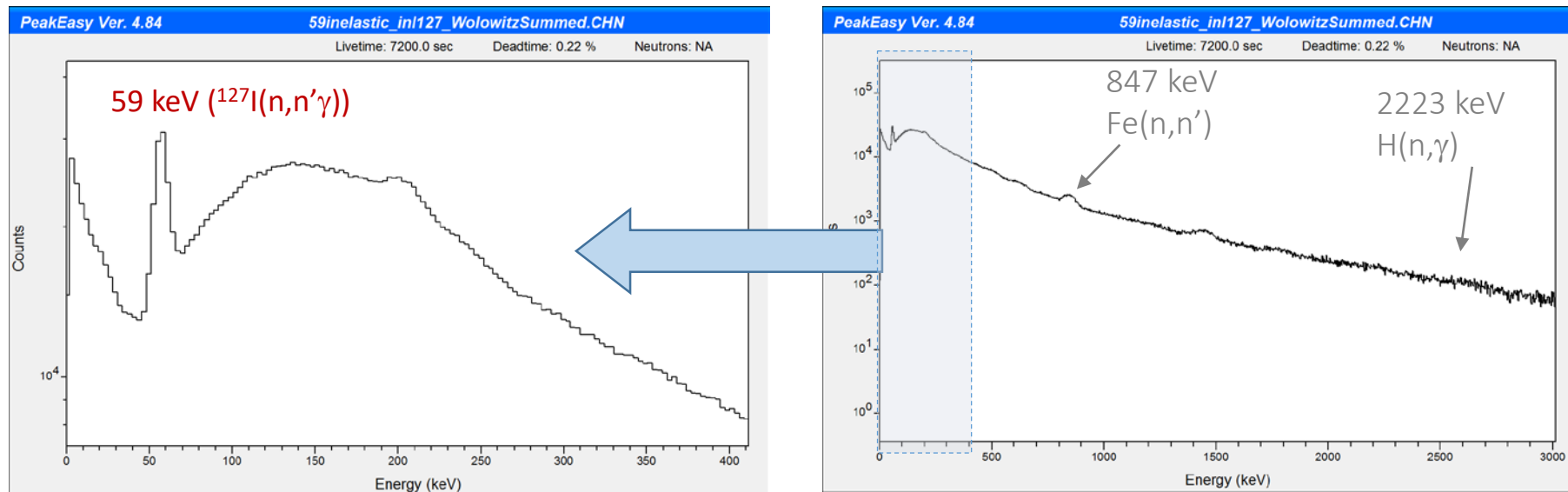


# Neutron Signatures in Gamma-Ray Spectra



# Neutrons & NaI

Fast neutrons on NaI can inelastically scatter off of  $^{127}\text{I}$  and produce a gamma ray at  $\sim 59$  keV.



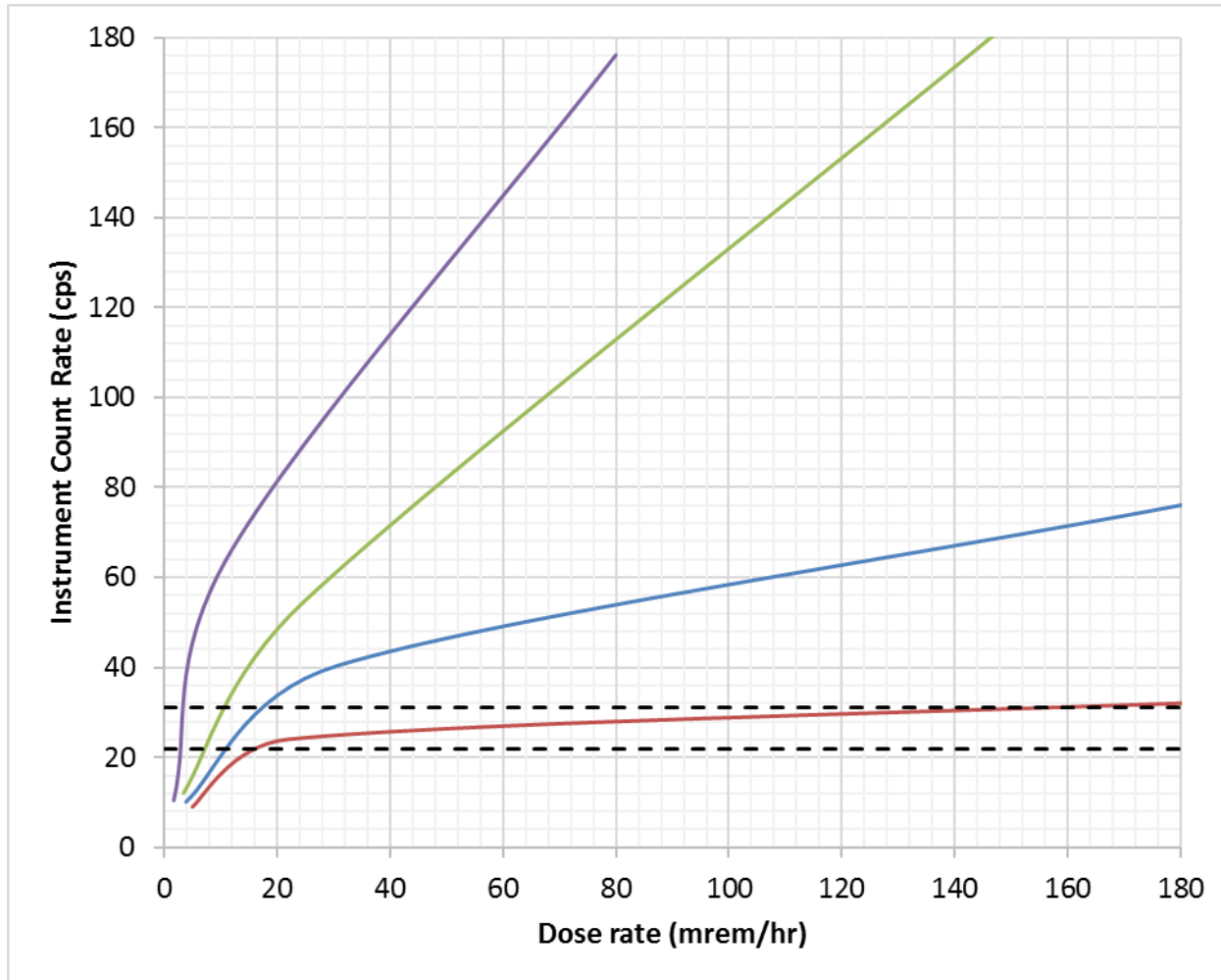
# Neutron Fluence to dose (mSv)

| Neutron energy<br>(MeV)          | Quality factor <sup>a</sup> (Q) | Fluence per unit dose equivalent <sup>b</sup><br>(neutrons cm <sup>-2</sup> mSv <sup>-1</sup> ) |
|----------------------------------|---------------------------------|---|
| 2.5 x 10 <sup>-8</sup> (thermal) | 2                               | 980 x 10 <sup>5</sup>   |
| 1 x 10 <sup>-7</sup>             | 2                               | 980 x 10 <sup>5</sup>   |
| 1 x 10 <sup>-6</sup>             | 2                               | 810 x 10 <sup>5</sup>   |
| 1 x 10 <sup>-5</sup>             | 2                               | 810 x 10 <sup>5</sup>   |
| 1 x 10 <sup>-4</sup>             | 2                               | 840 x 10 <sup>5</sup>   |
| 1 x 10 <sup>-3</sup>             | 2                               | 980 x 10 <sup>5</sup>   |
| 1 x 10 <sup>-2</sup>             | 2.5                             | 1010 x 10 <sup>5</sup>  |
| 1 x 10 <sup>-1</sup>             | 7.5                             | 170 x 10 <sup>5</sup>   |
| 5 x 10 <sup>-1</sup>             | 11                              | 39 x 10 <sup>5</sup>  |
| 1                                | 11                              | 27 x 10 <sup>5</sup>  |
| 2.5                              | 9                               | 29 x 10 <sup>5</sup>  |
| 5                                | 8                               | 23 x 10 <sup>5</sup>  |
| 7                                | 7                               | 24 x 10 <sup>5</sup>  |
| 10                               | 6.5                             | 24 x 10 <sup>5</sup>  |
| 14                               | 7.5                             | 17 x 10 <sup>5</sup>  |
| 20                               | 8                               | 16 x 10 <sup>5</sup>  |

<sup>a</sup> Value of quality factor (Q) at the point where the dose equivalent is maximum in a 30-cm diameter cylinder tissue-equivalent phantom.

<sup>b</sup> Monoenergetic neutrons incident normally on a 30-cm diameter cylinder tissue-equivalent phantom.

# Instruments' response to neutrons



- Common field RIID
- Dose rate taken with a REM ball (tissue equivalent)
- Different amounts of neutron shielding
  - You don't know what you have
- Rare to find  $> 1$  mSv neutron sources
- $32 \text{ CPS} = 30\mu\text{Sv} - 1.6 \text{ mSv}$